PNT Symposium Stanford University
China’s High Speed Railway Application with GNSS

Jin Shi 2015.11

Beijing National Railway Research & Design Institute of Signal & Communication Co., Ltd (CRSCD)
Outline

• China’s High Speed Railway
• GNSS Application in Railway
• GNSS Performance Study
• GNSS Special in Railway Application
• GNSS Enhancement Tech
• Future Application
• Summary
China’s High Speed Railway

• Brief History of China’s High Speed Railway
  – Introduced on April 18, 2007
  – 4x4 PDL network has been finished by 2014
  – Operational speeds of up to 380 km/h (240 mph)
  – Daily ridership has grown from 237,000 in 2007 to 2.49 million in 2014
  – Cumulative ridership had reached 2.9 billion by October 2014
  – World Largest HSR Network
China’s High Speed Railway

- Railway Map of China 2015
  - HSR line length exceeds 16,000KM (9900mi) in 2014
  - Combined with hybrid lines the length exceeds 20,380 km (12,660 mi) in 2014
  - 16,775 km (10,423 mi) is under construction
  - HSR network will double in 2020
Railway map of China
Colored lines showing CRH and other high speed rail services
Last update: 2015-09-30

- Blue lines: Lines capable for speed above 300 km/h
- Green lines: Newly built lines capable for 200-299 km/h
- Orange lines: Upgraded lines and other lines with CRH service
- Gray lines: Conventional lines with no CRH service
China’s High Speed Railway

• China’s HSR Network in 2020
  – 28/32 provinces and regions are connected
  – Redefine city distance, 8 hours between core metropolis
  – Challenge to traditional railway control system
  – Revolution for transportation industry
China’s High Speed Railway

- The Role of CRSC in China’s HSR History
  - Standard Contributor
  - System Design Solution Provider
  - Core Control System Manufacturer
  - Project Contractor and Executor
  - System Maintainer
GNSS Application in Railway

• Why China has Fantastic Construction Speed
  – Scientific planning and organization
  – Frontier design and verification technology
  – “Know How” experience during construction
  – Complete autonomy and fully customized Capability

• GNSS data plays important role for Railway
  – Early stage simulation
  – Rapid and accurate construction
  – ITCS control system
  – UAV for OAM
GNSS Application in Railway

• China’s Contribution to GNSS
  – Brief history of Compass Navigation System
    • BeiDou-1 System—2000-2003, bidirectional System, geostationary orbit
    • BeiDou-2 System—20012-Now, bidirectional System, hybrid orbit
      • free civilian service has a 10-meter location-tracking accuracy, synchronizes clocks with an accuracy of 10 nanoseconds, measures speeds to within 0.2 m/s.
      • restricted military service has a location accuracy of 10 centimeters
GNSS Application in Railway

- Coverage Area of Compass System
  - BeiDou-1
    - 70°E to 140°E
    - 5°N to 55°N
  - BeDou-2
    - 55°E - 180°E
    - 55°S - 55°N
GNSS Application in Railway

- **Roadmap of Compass System**
  - B1: 1559.052~1591.788MHz
  - B2: 1166.22~1217.37MHz
  - B3: 1250.618~1286.423MHz

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<th>Time</th>
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## GNSS Application in Railway

### Launch Plan of BeiDou in 2016

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GNSS Application in Railway

• Early Design Simulation
  – Determine the location of communication base station
  – 3D Modeling and integrated with GIS system (Google Earth)
  – Typical environment confirmation
  – Geometry parameter abstraction
  – Antenna feed system 3D modeling
  – Rough performance simulation
  – Channel sounding and data acquisition
  – Fine grain performance simulation
GNSS Application in Railway

- Early Design Simulation
  - For HSR lines
  - For Inter-City lines
  - For Metro lines
- Early Design Simulation
  - Antenna feed System Simulation
GNSS Application in Railway

- Early Design Simulation
GNSS Application in Railway

- ITCS Control System
  - First line using ITCS is Tsinghai-Tibet line – West area, wide plain terrain

- RAIMS requirement for ITCS Control System
  - Reliability
  - Accuracy/Availability
  - Data Integrity
  - Maintainability
  - Safety Integrity
GNSS Application in Railway

- GNSS System in Qinghai-Tibet Line
  - GNSS Combined Satellite System
GNSS Application in Railway

• UAV for OAM
  – RF signal measure
  – Power line check
  – Line measurement before construction
GNSS Performance Study

• Flat Area Case Study
  – Error bound within 10m
测量地面上两个点之间的距离

地图长度：10.62 米
地面长度：10.62
方位：229.22 度数
GNSS Performance Study

• City Area Case Study
  – Error can not be bound within 10m
• Point Jitter
GNSS Performance Study

- Point Jitter
GNSS Performance Statistics

- Signal Shift
  - Always happen near the station
测量地面上两个点之间的距离

地图长度： 38.89 米
地面长度： 40.41
方位： 217.70 度数
GNSS Performance Statistics

• Signal Lost
  – Always happen in the long tunnel
GNSS Special in Railway Application

- High speed, High reliability, High Accuracy
  - Speed > 380KM/H
  - MTBF > $10^9$ hours
  - Accuracy < 2m
  - Small antenna size
  - Response Time < 1s

- Fit for mass construction
  - Easy to deploy
  - Easy to maintain (depopulated zone)
  - Environment friendly
GNSS Special in Railway Application

• 2 Dimension, Different requirement
  – Along the running direction, 5s tolerance, 500m for HSR
  – Perpendicular to the running direction, < 2 meter
  – Fast locating time < 1s

• Real track is 1.5D not real 3D
  – No need to calculate 3D cordination
  – Time shift is enough for calculation
  – Track coordinate can be exactly known in advance

• Special enhancement tech can be used
  – Get fast converge rate
  – More accurate result
GNSS Enhancement Tech

- Dimension Reduction Enhancement Tech
  - Using the accurate geometry coordinate of the track
  - Using the satellite NAV telegram to get the satellite orbit
  - Pre-calculate the distance of every reference point at reference time point
  - All the pre-calculated data can be download to the GNSS receiver before the train is started.
GNSS Enhancement Tech

• Dimension Reduction Enhancement Tech
  – Traditional GNSS equation solves 4 unknowns
  – 4 satellites are needed to form 4 independent equations
  – Introduction of time table function $H(t)$ to reduce unknowns
\[ \| H(t_1 + \Delta t) - PS1(t) \| = \rho_{t_1,p}^1 + bc(T_{t_1}^{s1} - T_{t_1}^{train}) \]

\[ \| H(t_1 + \Delta t) - PS2(t) \| = \rho_{t_1,p}^2 + bc(T_{t_1}^{s2} - T_{t_1}^{train}) \]

\[ \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} + bc = p_i, \; i = 1, 2, \ldots, n \]

\( \rho_{t_1,p_1}^1 \rho_{t_1,p_1}^2 \) accurate value are exactly known

\( \rho_{t_1,p_2}^1 \rho_{t_1,p_2}^2 \)

Can be calculated because satellite and point position are known

\( \rho_{t_2,p_1}^1 \rho_{t_2,p_1}^2 \) accurate value are exactly known

\( \rho_{t_2,p_2}^1 \rho_{t_2,p_2}^2 \)
Time Table of WuHan-ShenZhen HSR Line 70% Throughput  2015.3.28

Position of the Train the Length from Ref Point

Time of Day
GNSS Enhancement Tech

• Direction Enhancement Tech
  – Using GSM-R communication network
  – Using LTE 4G network location reference signal
  – Using base station ID to get running direction
  – Avoid head on collision in low position accuracy
  – Using Time table function to add reference point via the balise or RF ID
  – Increase the accuracy on intersection plane
GNSS Enhancement Tech

- Direction Enhancement Tech
GNSS Enhancement Tech

• Time domain Enhancement Tech

  – Once the time is sync with satellite then the initial position can be get through time table $H(t)$ function immediately
  – Using time domain continuity to correct position error
  – Improve error correction process especially in station
  – Big data analysis process (Human Control/ATO Control)
• Geometry domain Enhancement Tech
  – Railway using special geometry curves, such as $y = \frac{x^3}{6RL}$
  – Using curvature and altitude to do 2D MSL match process to accelerate the convergence of GNSS search process
  – Using geometry continuity to correct coordinate
  – Greatly reduce the probability of jitter
• Result

– For simple geography situation, accuracy and response time can be improved a lot

– For complicated geography situation, the reliability of GNSS system even using enhancement tech still needs improvement although is rare(Murphy’s Law)

– More reliable and stable methodology is still on its way
Future Application

• Low Cost Railway System
• HSR Control System Enhancement
• Collision Warning System
• Smart OAM System
Summary

• GNSS is important to railway construction
• GNSS combined with enhance tech can get fantastic improvement for railway application
• The cost of accurate GNSS system can be under control
• Future usage of GNSS in unmanned railway vehicle (URV) is very promising
Thank you

Q&A

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